HATCHERY PRODUCTION OF WESTERN AUSTRALIAN SCALLOPS

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Adult scallops (*Amusium balloti*, *Chlamys australis* and *Chlamys scabricostata*) from Shark Bay, Western Australia were transported to 6,000l and 12,000l pools of raw seawater at a commercial hatchery. Adults were fed daily with cultured microalgae to improve gonad condition. Successful, induced spawnings were conducted for all species with *A. balloti* spawnings conducted in all months from April to December inclusive, over a 3 year period. Adults were induced to spawn by the addition of sperm and a water temperature increase. For the most successful batches, larvae were respectively reared to settlement in 12, 12 and 17 days at 22.2±0.94°C, 24.35±1.2°C and 20.2±0.8° C. Up to 6.1 million pediveligers were placed into settling tanks from one spawning. Batches of settled spat regularly exceeded 0.5 million with the highest count attained of approximately 2.4 million spat at the completion of the metamorphosis/settlement stage. Large scale hatchery production techniques were developed and a potential for aquaculture has been shown, particularly for *C. australis*.

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Ten species of scallops have been documented in W.A. waters (Wells & Bryce,1985) but an accurate number or species is difficult to obtain due to species overlap and name changes.

Of commercially important W.A. species, only *Amusium pleuronectes australiae* (Habe,1964) was omitted from Wells & Bryce's list; it was also omitted from a record of scallops in Shark Bay (Slack-Smith,1990). It is occasionally part of the by-catch of the *Amusium balloti* (Bernardi, 1861) fishery and forms the basis of a small fishery in the Northern Territory (Young & Martin,1989). Other commercial species are *Pecten modestus* (Reeve,1852), *Chlamys australis* (Sowerby, 1842), *Chlamys (Mimachlamys) asperrimus* (Lamarck,1819), *Annachlamys leopardus* (Reeve,1853) and *Amusium balloti*. *Pecten fumatus* Reeve,1852 may occur along the southern coast of W. A. (Joll, 1988) but hatchery production of it is documented (Cropp,1988a; Cropp & Frankish,1988; Dix & Sjardin,1975). *A. balloti* and *A. pleuronectes australiae* belong to the Amusiidae; other species mentioned above belong to the Pectinidae.

Of recent studies on hatchery production of Australian scallops (Connolly,1990; Cropp, 1988a, Cropp & Frankish,1988; Dix & Sjardin, 1975; Rose et al.,1988; Rose & Dix,1984) only one (Rose & Dix,1984) dealt with *Chlamys* as its commercial importance in Australia has been minimal; two (Connolly,1990; Rose et al.,1988) reviewed hatchery culture trials on *A. balloti*.

Rose & Dix (1984) provided information on larvae of the doughboy scallop, *Chlamys asperrimus*, which is similar to *C. australis* from W.A. They occupy similar ecological niches but the temperature regimes of their environs are 9–20°C for *C. asperrimus* and 17–25°C for *C. australis* (Cropp,1993b)

A. balloti, the saucer or swimming scallop, is the target species for significant trawl fisheries in central Queensland (Williams & Dredge,1981) and Shark Bay, W.A. (Joll,1987). It is a tropical-subtropical species which appears to prefer 19-24°C water on medium to coarse sandy mud bottoms. Its natural spat settlement and recruitment have been studied (McDuff,1975; Kettle, 1984; Dredge,1981; Campbell,1987; Sumpton et al.,1990) as has hatchery culturing (Rose et al., 1988; Connolly,1990). These studies were hindered by the tendency of the metamorphosing larvae not to exude a strong byssal thread (Rose et al.,1988; Dredge,1981). The attachment was also found to be for a short time period only (Rose et al.,1988), unlike *Pecten* or *Chlamys* (Dix & Sjardin,1975; Rose & Dix,1984; Sause et al., 1987; Hortle & Cropp,1987; Cropp,1993a). Improvements in broodstock conditioning and larval rearing techniques (Gwyther et al.,1991; Cropp,1988a) have been implemented and further developed in the study reviewed herein.

In Shark Bay the scallop by-catch of the *A. balloti* fishery is c.1–5% *C. australis*, *C. scabricostata* and *A. leopardus* (plus occassional rarer species). This by-catch is generally returned to the sea as processing is deemed difficult and markets have not been established. However, the meat and gonad from processed *C. australis* is

almost identical to that from the cooler water *C. asperrimus*, which is common in Tasmania and well received on the market. Hence a potential exists for marketing *C. australis*. *Chlamys scabricostata* does not grow to the same adult size that *C. australis* or *C. asperrimus* does (S. Slack-Smith pers. comm.). *C. australis* was deemed as having a better potential for aquaculture.

The most common spat production technique for overseas scallop culture is based around collection of natural spat at sea (Ito,1988; Bull, 1988). From this perspective alone, it is necessary to be able to distinguish between larvae which are likely to be present in the water column at similar times. For this reason a small scale hatchery trial involving *C. scabricostata* was conducted prior to the culture of *C. australis*. Adults of this species were induced to spawn and the larvae reared under the same conditions as for *C. australis*. Larvae produced by *A. balloti* adults have been reared under similar conditions and are distinguishable from *C. australis* and *C. scabricostata*.

Various *Chlamys* species are cultured in hatcheries and in some areas grown-out in culture operations overseas (Broom & Mason,1978; Mason,1983; Cropp,1988b). *Chlamys* generally attach firmly to substrates upon settlement and remain attached for several months. Interception of the natural settlement and spat attachment process (with artificial substrates) has been found to be viable (Hortle & Cropp,1987) and economically feasible on a large scale (Rhodes & Widman,1980; Maru,1985; Cropp,1987) for numerous different species overseas and within Australia (Bull,1988; Cropp,1988b). It has allowed industries to develop through the availability of large amounts of spat.

Amusium, however, exhibits a weak and temporary attachment (byssus) only (Dredge,1981; Gwyther et al.,1991) and collection of significant quantities of spat at sea is therefore unlikely. This necessitates the hatchery production of spat. The small population of *C. australis* in Shark Bay, suggests that natural spatfall would probably be minimal and thus, if an aquaculture industry was to develop for this species, hatchery culture would also be necessary. Significant quantities of *C. scabricostata* would probably be obtainable from spat collectors deployed in Shark Bay, hence the hatchery trial simply examined larval development in this species.

An assessment of meat recovery (as % of live weight) from various species suggested that most market potential was in *A. balloti* and *C. australis*. Larval development of these species was carefully examined in addition to a brief larval rearing trial with *C. scabricostata*. The southern species, *P. modestus* is acknowledged to have aquaculture potential also. The fact that it is similar to *P. fumatus*, which has been produced in commercial quantities in a hatchery, suggests that the larval rearing techniques for both species would probably be similar. Thus no special effort was made to rear the species in a hatchery. As an aquaculture species, *A. leopardus* was perceived to be inferior due to slow growth and relatively low meat recovery from live weight; consequently no hatchery work was conducted on this species.

MATERIALS AND METHODS

Saucer scallops were collected from trawlers in Shark Bay, between April and October of each year from 1989 to 1991. Broodstock for the *C. scabricostata* spawning were collected in June 1990, and for the *C. australis* spawning in July 1991. The scallops were obtained from sorting trays, placed into either small portable tanks containing aerated water or into steel mesh baskets in the vessels' circulating tanks. Scallops held in the vessels tanks were placed into small portable tanks upon arrival in port. They were transported in the tanks, by road, to a hatchery at Carnarvon and placed in 6000l and 12000l above-ground swimming pools, at c.15–20°C, for 5 days prior to a spawning being attempted with some of the animals. In mid-winter, 2 kW electrical immersion heaters were used to maintain the water temperature.

Saltwater was pumped through cartridge filters in the series: 20μm, 10μm, 5μm, 2μm and 1μm. Broodstock pools were filled with 20μm filtered water, larvae tanks with 1–20μm filtered water, depending on the daily water quality (thorough filtering for dirty water), and 1μm filtered water was used for algal cultures.

During the broodstock holding period, 50% of the pool volume was changed at least every second day and on occasions daily. Initially, volumes of a non-axenic algal culture, *Tetraselmis suecica*, were added daily in sufficient quantity to establish a food cell density in the holding pool of 30000–40000 cells ml^{-1}. After early gonad conditioning work exhibited poor results, the algae species was changed to another non-axenic alga, *Chaetoceros gracilis*. When available, this diet was supplemented (with approximately 5000 cells ml^{-1}) by non-axenic

TABLE 1. Average annual results for each of the development stages per spawning batch of *A. balloti*.

Year	No. of Batches	No.Females	F	D	P	Pediveliger Size (μm)	Days to settlement
1989	19	13.26	27.4005	1.4298	68658	202.45	15.40
1990	11	12.91	21.9327	0.8896	496,667	212.82	14.30
1991	5	9.00	18.5000	2.7420	1,765,000	211.00	11.75

F= No. Fertilized eggs (x 10^6); D= No. 'D' veligers (x 10^6); P= No. Pediveligers (Cropp,1993a)

TABLE 2. Average annual size and growth rates of *A. balloti* larvae per batch. Only batches where an accurate Day 2 and pediveliger size were available are documented in this table, hence the batch and pediveliger difference to Table 1. Pediveliger size is taken as the larval size on settlement day (Cropp,1993a).

Year	No. of Batches	Size (μm)	Size of 'D' larvae, day 2(μm)	Pediveliger size (μm)	Days to settlement	Daily growth of larvae, day 2 to settlement (μm day^{-1})
1989	10	75	114.56	201.78	15.40	5.66
1990	5	75	119.70	214.38	14.30	6.62
1991	4	75	123.30	211.00	11.75	7.46

Chaetoceros calcitrans, *Pavlova lutheri* and Tahitian *Isochrysis (aff.) galbana*.

Gonad condition of live scallops was monitored visually on a regular basis. When well developed or mature gonads were apparent, selected animals were cleaned and a spawning was attempted. In most spawnings, 4–10 male and 10–20 female *A. balloti* were used. For the other spawnings, 3 male and 6 female *C. australis*, and 2 male with 4 female *C. scabricostata* were used. A combination of water temperature increases and the addition of sperm extracted from spare broodstock were used as spawning stimuli.

RESULTS

Thirtyfive successful spawnings of *A. balloti* were conducted over the 3 years (Cropp, 1993a)(Tables 1,2). A maximum of about 6 million and often in excess of 3 million eggs were obtained from *A. balloti* females, up to 4.5 million eggs from *C. australis* females and about 0.5 million eggs per *C. scabricostata* female resulted from induced spawnings (Cropp,1993b).

Larvae were reared in larvae tanks at a salinity of 35ppt and an average temperature of 22.2± 0.94°C (mean±s.d.) for *A. balloti*, 24.35±1.2°C for *C. australis* and 20.2±0.8°C for *C. scabricostata*. The algal diet was composed of similar portions of *C. calcitrans*, *P. lutheri* and Tahitian *I. (aff.) galbana* at a density increasing from 10000 cells ml^{-1} on day 2 up to 15000 cells ml^{-1} at day 12 (settlement) and then to 25000 cells ml^{-1} for settled spat. The diet of one batch of *A. balloti* larvae reared in July-August 1991 (Fig.1) is representative of that fed to other larval batches. Larval water was changed totally on or about every two days. For the most successful batches, larvae were respectively reared to settlement in 12, 12 and 17 days (Cropp,1993a,b).

Larval development for *A. balloti* commenced with eggs of 75.9±4.4μm (n=40), a first 'D' stage veliger (day 2) of 123.3±2.06μm and a pediveliger of 211.0±1.41μm (Fig.2). Larval development of *A. balloti* as documented (Rose et al.,1988) was verified in this work. For the batch being examined, 4.1 million pediveligers were put into settlement tanks with 30 mesh spat

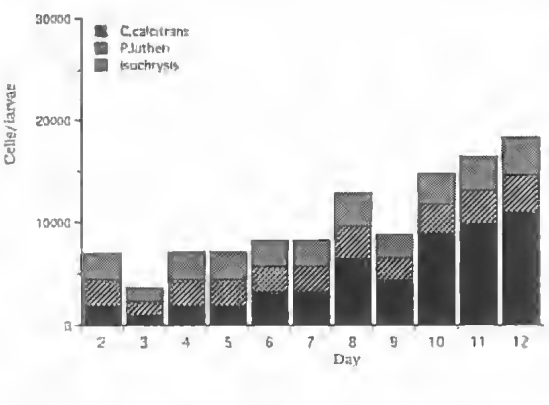

FIG. 1. Algal diet for *A. balloti* larvae during the culture phase, July-August 1991.

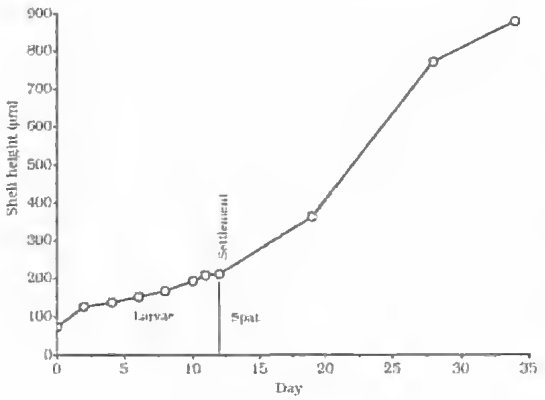

FIG. 2. Growth of *A. balloti* larvae and spat, July-August 1991 (Cropp,1993a).

collectors. On day 19 spat were 362 µm in size, and by day 28, 1.4 million spat of 772 µm in size were present (41,333±4,509 spat/collector plus 160,000 loose spat). The shell of spat gradually changed from opaque to white as they grew (>4mm), a feature which has not been documented previously. It is also an aspect to be considered when identifying naturally occurring spat collected in tropical and sub-tropical areas.

Mature eggs of *C. australis* were 62.2±2.2µm (n =30) and the first D-shaped larvae were 108.5±4.1µm long (Fig.4). Total eggs produced from the 4 females was 12.55 million (Fig.5). By day 4 the larvae measured 124.1±5.0µm long. The D- shaped larvae developed rapidly up to day 8 when a characteristic scallop larval shape was displayed.

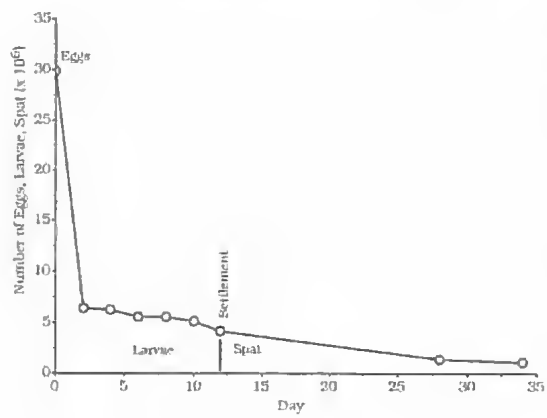

FIG. 3. Number of *A. balloti* eggs, larvae and spat surviving during the culture phase, July-August 1991 (Cropp,1993a).

Precise size of fully developed pediveligers is difficult to ascertain; for *C. australis*, a sample of swimming pediveligers taken on day 12 had a mean length of 203.6±12.1µm. At that stage c.50% of the larvae had an motile foot. A sample of settled spat on day 15 had a length of 296.9±48.3 µm. Thin new (dissoconch) shell was evident on the outer edge of spat. About 2.4 million spat (39.3%) settled from 6.1 million eyed larvae at day 12. The spat count included an estimation of those spat attached to the wall and bottom of the tank. A sample of 5 collectors was washed and spat counted on day 16. The mean count per collector was 37,800±6,058; spat were approximately 300µm.

Eggs produced by *C. scabricostata* females had a diameter of 60–63µm (Fig.6). Sufficient sperm

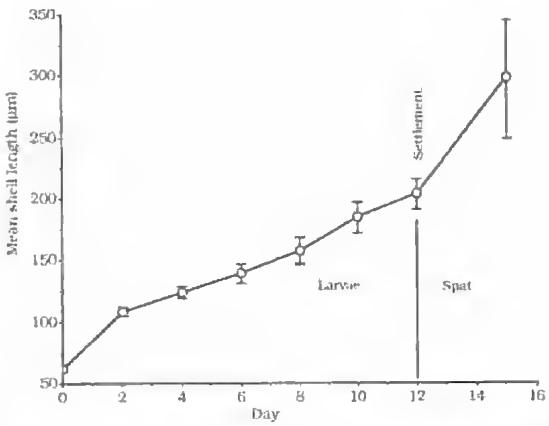

FIG. 4. Growth of *C. australis* larvae and spat: (shell length with s.d.); (n = 30) (Cropp,1993b).

solution was added to give a ratio of 4–5 sperm per egg (with a total of 1.54 million eggs, Fig.7). After 46 hours (day 2) at 21.8°C, 800,000 larvae (51.95% of eggs) had developed into D-shaped veligers with a mean length of 103.4µm (Figs 6,7) and 82.2µm height. At day 13 the larvae were 197µm long and exhibited a prominent eye-spot. By day 17 numerous pediveligers were evident. The 75,000 remaining larvae were 220µm long and had grown at a rate of 8.33µm day^{-1} since becoming D-shaped larvae at day 2. Metamorphosis and settlement occurred over days 17–20. By day 21 settled spat were 250µm long and exhibited new shell.

DISCUSSION

Examination of the commonly assessed phases

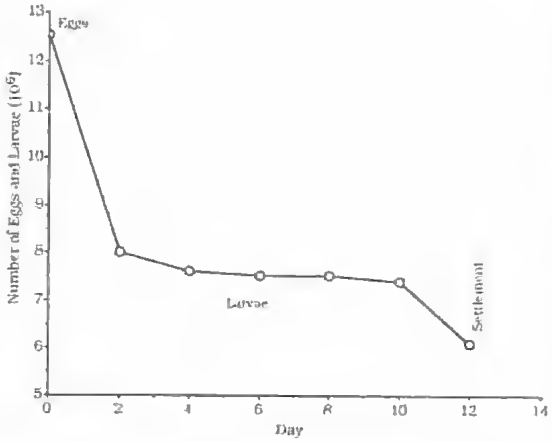

FIG. 5. Number of *C. australis* eggs and larvae surviving during the culture phase (Cropp,1993b).

of the larval rearing stage for *A. balloti* indicated that culture in 1991 was markedly more successful than culture of larvae in 1990 and especially 1989. A combination of factors was responsible for this success. The major improvements were in broodstock conditioning, and thus quality of eggs, the effectiveness of the water filtration system (improved water quality) and variations in the larval culture conditions (Cropp,1993a).

Use of high quality mature eggs produced benefits throughout the larval culture period. Less mortality occurred and larger veligers resulted. Subsequent use of water with a stable temperature and salinity further enhanced the growth and survival of larvae.

An average survival figure in 1991 of 14.8% from eggs to D-shaped larvae and 64.4% from D-shaped larvae to pediveligers compares favourably with data from Canadian research (Thompson et al.,1985) on the Japanese scallop *Patinopecten yessoensis*. Larval rearing of this species produced survival rates for corresponding phases of 10% and 10%. These figures may have resulted from the use of antibiotics and non-axenic algae in the culture process.

Rose et al. (1988) recorded a growth of 5.2μm day^{-1} for *A. balloti* larvae from the first D stage to the umbonal veliger, then 6.3μm day^{-1} until the pediveliger stage. Larvae in our study attained an overall average (for 1991) of 7.5μm day^{-1} for the period from the first D-shaped larvae (day 2) to pediveliger. The batch spawned on 24 July 1991 gave an overall growth rate of 8.7μm day^{-1} for the same phase.

Rose & Dix (1984) found that the mean egg diameter for *C. asperrimus* was 61.5±0.4μm, the first D-shaped larval stage with a prodissoconch I shell occurred after 2 days and was 108μm long, and that fully developed pediveligers occurred on day 19, when larvae were 194μm long. Corresponding data for *C. australis* were 62.2± 2.2 μm, 108.5±4.1μm and 203.6±12.1 μm (day 12) respectively.

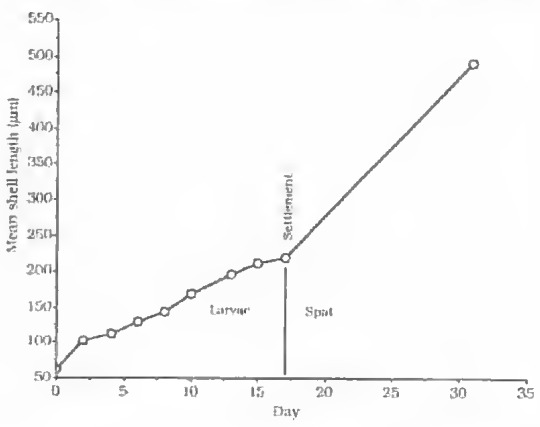

FIG. 6. Growth of *C. scabricostata* larvae and spat: (shell length).

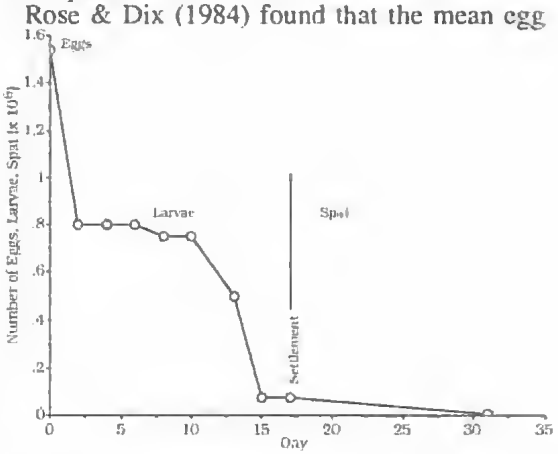

FIG. 7. Number of eggs, larvae and spat for *C. scabricostata* during the culture phase.

C. australis larvae were reared at 23–24°C in a subtropical area, whilst *C. asperrimus* larvae (Rose & Dix,1984) were reared at 17–18°C in a cool temperate area. The higher rearing temperature for *C. australis* is thought to be responsible for the comparatively short larval period.

Larval development appears to be very similar for *C. asperrimus* and *C. australis* and the spat settle at a similar size. In the *C. australis* trial, 63.7% of eggs developed into D-shaped larvae,

76.3% developed from D-shaped larvae to metamorphosis and overall, 48.6% of eggs developed through to metamorphosis. These are extremely high survival rates and as far as known, they exceed those documented for hatchery culture of any other species of scallop world-wide.

Overall, these trials have established viable techniques for the production of commercial quantities of *A. balloti* and *C. australis*. For *A. balloti* this may mean that large quantities of spat could be used to enhance the wild fishery, although this is unlikely to be required at present due to the buoyant state of the fishery. Catches recorded recently in W.A. have been higher than previous peaks in the history of the fishery. Associated declines in market value, and a depressed world scallop market, have threatened the commercial viability of the scallop trawling industry and eliminated the possibility of a viable culture industry at present. For *C. australis*, hatchery produced spat may allow its aquaculture potential to be developed as it has been for *C. asperrimus* in Tasmania. However, the economic value of *C. australis* would be affected by the depressed market and commercial viability of a culture operation would need careful examination before proceeding.

ACKNOWLEDGEMENT

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